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Temporal variation and ecological parameters of hawkmoths (Lepidoptera: Sphingidae) in savannahs in the Alter do Chão protection area, Santarém, Pará, Brazil

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ABSTRACT. This study evaluated the seasonality of Sphingidae spp. in two areas of savannah, in the eastern Brazilian Amazon, sampled for one year (June, 2014 through May, 2015) with the aid of Pennsylvania light traps placed at four sampling points. Data on fauna were obtained through the following parameters: abundance (N), richness (S), composition, Shannon diversity and uniformity indices (H' and U'), and the Berger-Parker (BP) dominance index. Richness estimates were calculated using Bootstrap, Chao1, ACE, Jackknife 1, and Jackknife2 estimators. The Pearson correlation was also used to analyze the effect of climatic variables such as rainfall, temperature, and relative humidity on richness and abundance. The result for the parameters analyzed during the entire sampling period was N= 374, S= 34, H'= 2.59, U= 0.733 and BP= 0.235. The estimation of richness showed that between 63% and 87% of expected species were collected (Bootstrap estimated 39 species and Chao1 estimated 54). The most representative species were: *Isognathus caricae* (Linnaeus, 1758) (N= 88), *Enyo lugubris lugubris* (Linnaeus, 1771) (N= 58), *Isognathus menechus* (Boisduval, [1875]) (N= 46) and *Cocytius duponchel* (Poey, 1832) (N= 44), with 54% of the sample containing species considered rare divided into 298 male and 76 female specimens. For climatic variables, there was a moderate positive correlation only between abundance and temperature. The less-rainy period presented greater richness (S= 26) and abundance (N= 222), and the rainy period had better indices for H' (2.55), U (8.01), and BP (0.230). The richness estimator Jackknife 2 was the best estimator in both sampling periods with 34 in the less-rainy period and 45 in the rainy period. The richness and abundance obtained in this study contribute significantly to the knowledge of Sphingidae fauna in an area of Amazonian savannahs.

Keywords: seasonal; moths; amazon.

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Introduction

The Brazilian Amazon contains approximately ¼ of the Amazon biome, considered to be the world's largest phytogeographic domain of tropical forests, 90% of which is composed of tropical forest with the remainder made up of other vegetation types such as savannah, floodplain forests, and areas subjected to annual flooding (Ab'Saber, 2002). Enclaves of savannah are characterized as Amazonian savannahs (Ab'Saber, 2002), which are little known, highly threatened and under-protected (Carvalho & Mustin, 2017) and occupy approximately 150.000 km² of the Amazon basin (Pires & Prance, 1985). In the State of Pará savannah is present on the island of Marajó, Alto Paru, Monte Alegre, the region of the Trombetas River, Santarém, Serra dos Carajás and Serra do Cachimbo (Pires & Prance, 1985). In the Santarém region a large part of the savannah resides in the Alter do Chão Environmental Protection Area (ACEPA) (Magnusson, Lima, Albernaz, Sanaiotti, & Guillaumet, 2008).

During recent years the Amazon biome has suffered degradation due to timber harvesting, fires, opening of new roads, deforestation, and construction of hydroelectric dams, resulting in the extinction of fauna, invasion of exotic species, and changes in climate that directly affect biodiversity (Junk & Mello, 1990; Fearnside, 1999; Ferreira, Venticinque, & Almeida, 2005). In the areas of savannah in the ACEPA the situation has not been any different in the last few years due to human activities that threaten its biodiversity and even the integrity of the ecosystem.

Insects perform many key functions in ecosystems because they are involved in diverse processes such as propagation of plants through pollination and seed dispersion, maintenance of the composition and structure of plant and animal communities, nutrient recycling, and diverse other ecological interactions with animals, plants, and microorganisms (Gullan & Cranston, 2012). Among the insects, the Lepidoptera order is one of the most important due to its great diversity and abundance of some of its species, with some of them contributing to pollination of Angiosperms, which are plant species that depend on these insects, among others, in order to reproduce (Duarte, Marconato, Specht, & Casagrande, 2012).

The moths from the Sphingidae family have great ecological importance due to insect-plant interactions, and for this reason they can be considered potential biological indicators of plant communities (Kitching & Cadiou, 2000; Hilty & Merenlender, 2000). In the Brazilian Amazon, taking into account its extensive territory and ecosystem diversity, there are relatively few studies of the Sphingidae (Rothschild & Jordan, 1910; Moss, 1920; Motta, Ferreira, & Aguiar, 1991; Motta & Soares, 1997; Motta, Aguilera Peralta, & Andreazze, 1998; Motta & Andreazze, 2001; Motta & Andreazze, 2002; Motta & Xavier Filho, 2005; Duarte, Motta, & Lourido, 2009; Hawes et al., 2009; Haxaire, 2009; Camargo et al., 2016). Of these studies only four were conducted in Pará (Moss, 1920; Motta & Soares, 1997; Hawes et al., 2009; Camargo et al., 2016), and only one was done in a savannah ecosystem (Motta et al., 1991), who studied savannahs in the Pacaraima Mountains.

Studies that analyze the faunal composition of the region enable the description of the community structure (Silveira Neto, Monteiro, Zucchi, & Moraes, 1995). Among the factors that can influence the occurrence of pollinating insects is temporal variation, principally in tropical regions where the availability of resources is directly related to variation in time (Van Schaik, Terborgh, & Wright, 1993). Studies of the effect of time on diversity can elucidate species' seasonal variation, demonstrating the principal period of occurrence of the species and thus allowing for better knowledge about the state of the fauna in an ecosystem (Teston, Novaes, & Almeida Júnior, 2012). Due to the scarcity and the importance of these studies in the Amazon, the objective of this work was to conduct a faunal survey of hawkmoths (Lepidoptera: Sphingidae) in areas of savannah in the ACEPA, with the goal of describing the species' richness, abundance, diversity, and composition, and verify whether or not there are seasonal differences in the occurrence of these species and correlations of abundance and richness with climatic variables.

Material and methods

This study was conducted in two areas of Amazonian savannah in the State of Pará within the Alter do Chão Environmental Protection Area (ACEPA) in the city of Santarém (Figure 1). The areas of savannah in this region have vegetation characteristic of Amazonian savannah according to the classification in Oliveira Filho and Ratter (2002), where grasses (*Paspalum carinatum* and *Trachypogon plumosus*), sedges from the Cyperaceae family, and shrubs (Magnusson et al., 2008) are dominant. The climate type is tropical humid – Ami in the Köppen classification, with annual average precipitation of 2,000 mm and average temperature oscillating between 24 and 27.8 °C (Miranda, 1993), and strong seasonal variation with December to May being the wet season and June to November the dry season (Moraes, Costa, Costa, & Costa, 2005). Monthly collections occurred between June 2014 and May 2015 at four sampling points with two in the community of São Pedro (S2° 32' 02.9" and W54° 54' 06.8"; 433 m from the forest edge, and S2°31' 30.8" and W54° 54' 06.1"; distant 532 m from the forest edge), and 940 m distant from each other. The other sampling area consisted of two points in the village of Alter do Chão (S2° 32' 26.8" and W54° 58' 04.4"; 136 m from the forest edge, and S2° 32' 27.7" and W54° 58' 35.2"; 201 m from the forest edge), and 960 m distant from each other (Figure 1).

Pennsylvania light traps (Frost, 1957), equipped with ultraviolet fluorescent lamps of type F15 T12 LN and wavelength between 290 and 450 nanometers were used. The traps were used from twilight through the night (18 h to 06 h). Each trap was coupled to a funnel and a bucket containing 92% ethyl alcohol, installed two meters from the soil surface, and energy for the lamps was generated using a 12-volt battery (Teston & Corseuil, 2004). At the end of the collection period the specimens were stored in bottles labeled with the sampling point, date and collector and were kept at the *Laboratório de Estudos de Lepidópteros Neotropicais* LELN at the *Universidade Federal do Oeste do Pará* (UFOPA).

The specimens were sorted, separated into morphospecies, identified for sex, prepared for display on extenders (two specimens), and dried in an oven at 50°C for 48 hours, and then stored in entomologic

drawers, provisionally identified according to D'Abrera (1986) and Kitching (2013), and subsequently verified by specialists.

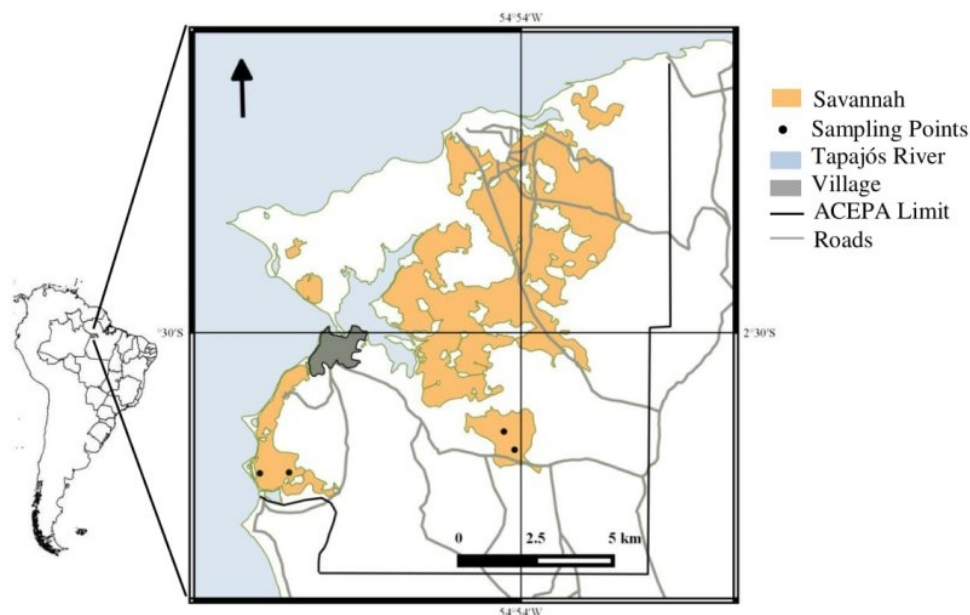


Figure 1. Location of sampling points in areas of savannah in the Alter do Chão Environmental Protection Area, Santarém, Pará, Brazil.

The remainder of the specimens was stored in entomological envelopes labeled with collection point, collector, and species number. All screening data for abundance, richness, by sampling point and month were stored in a computer spreadsheet. The reference collection material was deposited in the Entomological Collection of the LELN.

The faunal parameters evaluated during the dry and wet seasons were abundance (N), richness (S), composition, Shannon diversity and uniformity indices (H' and U'), and the Berger-Parker (BP) dominance index. The H' values between periods were compared using a t-test using the software PAST (version 3.01) (Hammer, Harper, & Ryan, 2001), in order to verify the statistical significance of the index (Magurran, 2011).

Dominance was calculated and classified according to Ott and Carvalho (2001), where: eudominants (most abundant species) are present in more than 10% of the samples; dominant species are present in 5 to 10% of the samples, and sub-dominants are present in 2 to 5 % of the samples. Species considered to be only occasional and rare are present in 1 to 2%, and less than 1% of the samples, respectively.

The program EstimateS (version 9.1.0) (Colwell, 2013), was used to calculate the estimates of richness using the parameters Chao 1, Jackknife 1 and 2, Bootstrap and ACE (Colwell & Coddington, 1994). These measurements allowed the estimation of total number of species in the study area using sample data as a base (Dias, 2004), where: Chao 1 is based on the abundance to estimate richness using the number of rare species in the sample; Jackknife 1 takes into consideration the number of species that were encountered only once (unicates), and Jackknife 2 uses the number of individuals encountered twice; Bootstrap does not limit itself to using just rare species but instead uses data from all species to estimate richness; ACE is based on the concept of sample coverage (singletons and doubletons) (Colwell & Coddington, 1994).

A species accumulation curve was used to evaluate the degree to which this study was able to capture all species present at the sampling points, based on the idea that when the sample size is larger a larger number of species will be encountered (Schilling & Batista, 2008).

A Pearson correlation was conducted using the software PAST in order to elucidate the degree of correlation between the rainy and dry seasons and species richness and abundance using the climatic variables rainfall, temperature, and relative humidity, data for which were obtained from the Climate database of the *Departamento de Controle do Espaço Aéreo* of the *Comando da Força Aérea Brasileira* (BDC – DECEA, 2015).

Results

Characterization of the fauna

The sampling yielded 374 specimens (N) distributed across 34 species (S) belonging to six different tribes (Table 1), with 298 males and 76 females. The Shannon diversity and uniformity indices were ($H' = 2.59$), and ($U = 0.733$), respectively, and the Berger- Parker dominance index was ($BP = 0.235$) (Table 2).

Table 1. Richness (S), abundance (N), and dominance (E= eudominant; D= dominant; S= sub-dominant; EV= occasional; and R= rare) of Sphingidae species collected in two seasons (dry and wet) using Pennsylvania light traps in areas of savannah in the Alter do Chão Environmental Protection Area, June 2014 to May 2015.

Subfamily/ Tribe/ Species	Dry (N)	Wet (N)	Total (N)
Macroglossinae (S= 26)	177	131	308
Dilophonotini (S= 21)	167	123	290
<i>Callionima inuus</i> (Rothschild & Jordan, 1903)		1 ^(R)	1 ^(R)
<i>Callionima parce</i> (Fabricius, 1775)	4 ^(EV)	14 ^(E)	18 ^(D)
<i>Enyo lugubris lugubris</i> (Linnaeus, 1771)	34 ^(E)	24 ^(E)	58 ^(E)
<i>Enyo ocypte</i> (Linnaeus, 1758)	19 ^(D)	2 ^(EV)	21 ^(D)
<i>Erinnyis alope</i> (Drury, 1770)		1 ^(R)	1 ^(R)
<i>Erinnyis crameri</i> (Schaus, 1898)		1 ^(R)	1 ^(R)
<i>Erinnyis ello ello</i> (Linnaeus, 1758)	2 ^(R)	14 ^(E)	16 ^(D)
<i>Erinnyis obscura</i> (Fabricius, 1775)	3 ^(EV)	1 ^(R)	4 ^(EV)
<i>Erinnyis oenotrus</i> (Cramer, 1782)		3 ^(EV)	3 ^(R)
<i>Hemeroplanes triptolemus</i> (Cramer, 1779)		2 ^(EV)	2 ^(R)
<i>Isognathus caricae</i> (Linnaeus, 1758)	53 ^(E)	35 ^(E)	88 ^(E)
<i>Isognathus leachii</i> (Swainson, 1823)		1 ^(R)	1 ^(R)
<i>Isognathus menechus</i> (Boisduval, [1875])	32 ^(E)	14 ^(E)	46 ^(E)
<i>Madoryx oiclus oiclus</i> (Cramer, 1779)	1 ^(R)		1 ^(R)
<i>Madoryx plutonius plutonius</i> (Cramer, 1779)	1 ^(R)	1 ^(R)	2 ^(R)
<i>Pachylia ficus</i> (Linnaeus, 1758)	2 ^(R)		2 ^(R)
<i>Pachylia syces syces</i> (Hübner, [1819])	1 ^(R)		1 ^(R)
<i>Pachylioides resumens</i> (Walker, 1856)	3 ^(EV)		3 ^(R)
<i>Perigonia lusca</i> (Fabricius, 1777)	4 ^(EV)	5 ^(S)	9 ^(S)
<i>Perigonia pallida</i> Rothschild & Jordan, 1903	4 ^(EV)		4 ^(EV)
<i>Pseudosphinx tetrio</i> (Linnaeus, 1771)	4 ^(EV)	4 ^(S)	8 ^(S)
Macroglossini (S= 3)	7	7	14
<i>Xylophanes chiron nechus</i> (Cramer, 1777)	3 ^(EV)	2 ^(EV)	5 ^(EV)
<i>Xylophanes loelia</i> (Druce, 1878)	3 ^(EV)		3 ^(R)
<i>Xylophanes tersa tersa</i> (Linnaeus, 1771)	1 ^(R)	5 ^(S)	6 ^(S)
Philampelini (S= 3)	5	1	6
<i>Eumorpha anchemolus</i> (Cramer, 1780)		1 ^(R)	1 ^(R)
<i>Eumorpha labruscae</i> (Linnaeus, 1758)	4 ^(EV)		4 ^(EV)
<i>Eumorpha phorbis</i> (Cramer, 1775)	1 ^(R)		1 ^(R)
Smerinthinae (S= 1)	3	5	8
Ambulycini (S= 1)	3	5	8
<i>Protambulyx strigilis</i> (Linnaeus, 1771)	3 ^(EV)	5 ^(S)	8 ^(S)
Sphinginae (S= 7)	41	15	58
Acherontiini (S= 1)	1	4	5
<i>Agrius cingulata</i> (Fabricius, 1775)	1 ^(R)	4 ^(S)	1 ^(EV)
Sphingini (S= 5)	40	11	51
<i>Cocytius duponchel</i> (Poey, 1832)	36 ^(E)	8 ^(D)	44 ^(E)
<i>Cocytius lucifer</i> Rothschild & Jordan, 1903	1 ^(R)		1 ^(R)
<i>Manduca diffissa</i> (Butler, 1871)	2 ^(R)	2 ^(EV)	4 ^(EV)
<i>Manduca florestan</i> (Cramer, 1782)		1 ^(R)	1 ^(R)
<i>Manduca rustica rustica</i> (Fabricius, 1775)	1 ^(R)		1 ^(R)
Total	223	151	374

With respect to dominance, four were eudominant (12%), three dominant (8%), four subdominant (12%), five occasional (14%), and 19 rare (54%). The eudominant species were: *Isognathus caricae* (Linnaeus, 1758) (N= 88), *Enyo lugubris lugubris* (Linnaeus, 1771) (N= 58), *Isognathus menechus* (Boisduval, [1875]) (N= 46) and *Cocytius duponchel* (Poey, 1832) (N= 44).

The richness estimate showed that this sampling collected between 63% and 87% of expected species. The Bootstrap estimated 39 species and Chao1 estimated 54 (Table 2), and this result supports those from the species accumulation curve which did not reach an asymptote (Figure 2a).

Table 2. Richness (S), Abundance (N), Shannon diversity (H'), and uniformity (U) indices, and Berger-Parker dominance (BP), and Sphingidae richness estimates collected in two seasons (dry and wet) using Pennsylvania light trap, in areas of savannah in the Alter do Chão Environmental Protection Area, June 2014 to May 2015

	Dry (N)	Wet (N)	Total (N)
S	26	24	34
N	222	152	374
H'	2.40	2.55	2.59
U	0.736	0.801	0.733
BP	0.239	0.230	0.235
Chao 1	32	32	54
Jackknife 1	33	36	46
Jackknife 2	34	45	54
Bootstrap	30	29	39
ACE	29	32	44
Singletons	7	8	11
Doubletons	4	4	3
Unicatas	7	12	12
Duplicatas	6	2	4

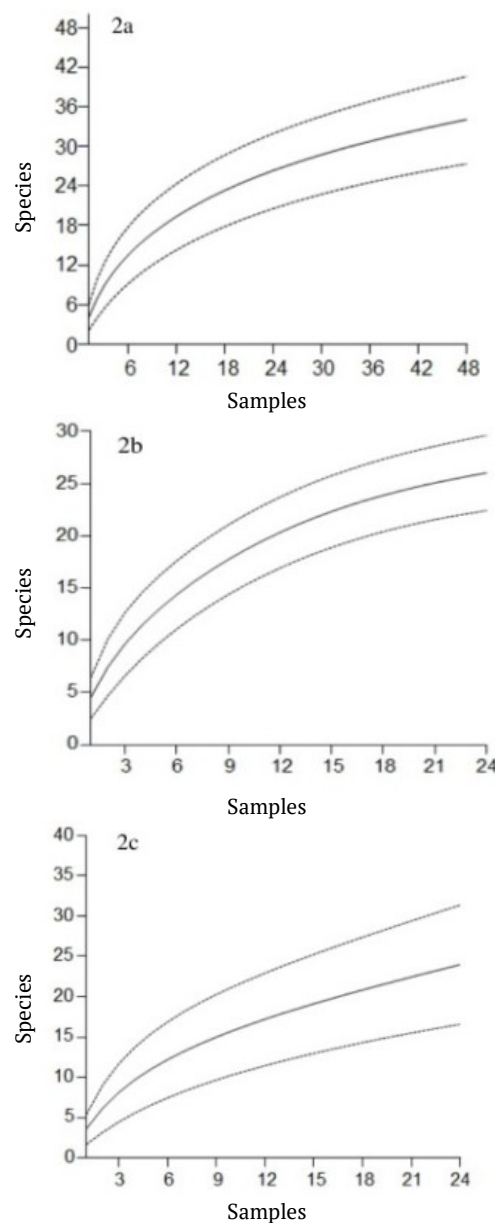


Figure 2. Accumulation curve for collected Sphingidae species, in function of sample size, using Pennsylvania light traps in areas of savannah in the Alter do Chão Environmental Protection Area, Santarém, Pará, Brazil, from June 2014 to May 2015, (2a) total sampling period, (2b) dry season, and (2c) wet season. Samples (solid line) and upper and lower 95% confidence intervals (dotted lines).

With respect to abundance, the correlations were moderate, positive and significant for temperature ($r = 0.5768$; $p < 0.049599$); moderate, negative and significant for relative air humidity ($r = -0.63301$; $p < 0.027146$); moderate, negative and not significant for precipitation ($r = -0.53502$; $p > 0.07307$) (Figures 3, 4, and 5, respectively). For the correlation of climate with species richness, there was no significant correlation, and the results were: temperature, positive and weak ($r = 0.34068$; $p > 0.27853$); relative air humidity, negative and moderate ($r = -0.45113$; $p > 0.14101$); and for precipitation, negative and moderate ($r = -0.40011$; $p > 0.19749$) (Figures 3, 4, and 5, respectively).

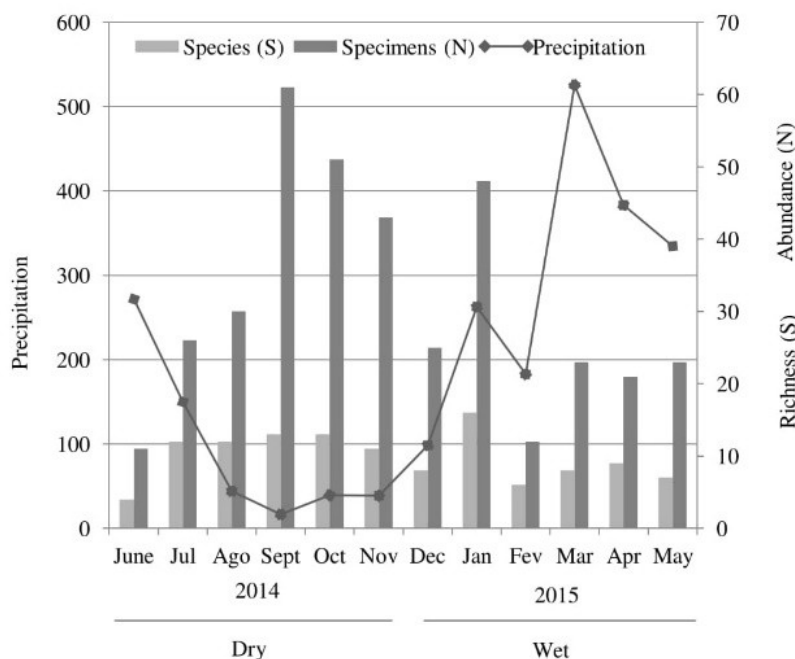


Figure 3. Richness (S), and Abundance (N) of Sphingidae species with total monthly precipitation, in mm, collected in the dry season (June to November) and wet season (December to May) using Pennsylvania light traps, in areas of savannah in the Alter do Chão Environmental Protection Area, June 2014 to May 2015

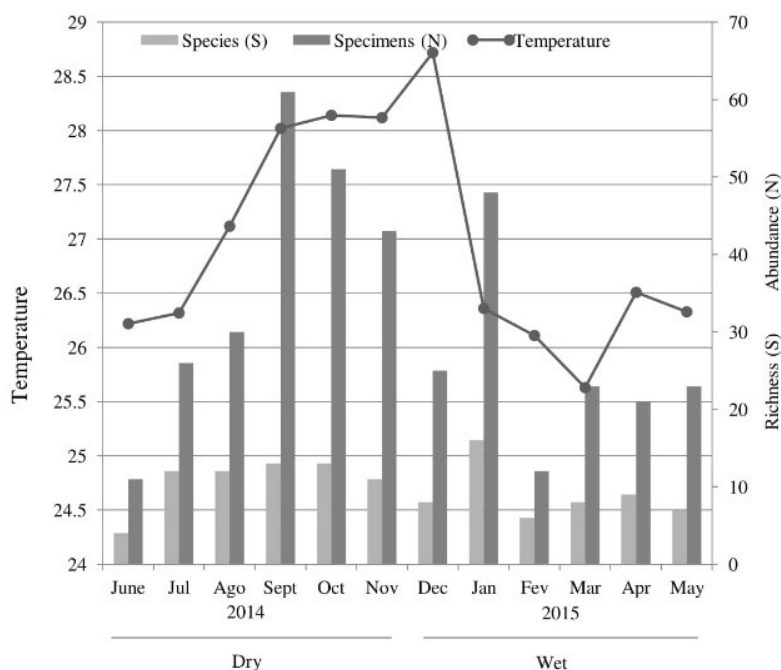


Figure 4. Richness (S), and Abundance (N) of Sphingidae species with average monthly temperature (°C), collected in the dry season (June to November) and wet season (December to May) using Pennsylvania light traps, in areas of savannah in the Alter do Chão Environmental Protection Area, June 2014 to May 2015

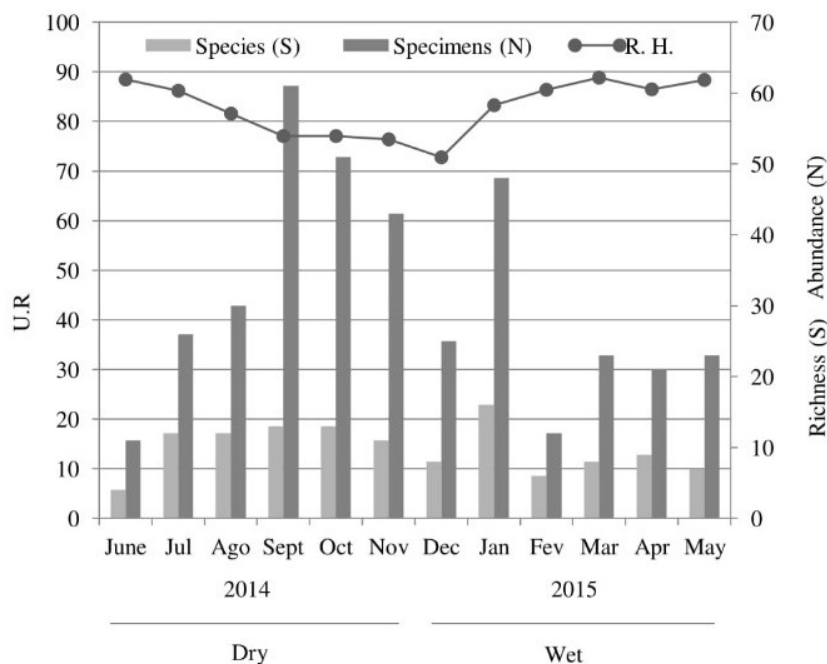


Figure 5. Richness (S), and Abundance (N) of Sphingidae species with percent relative humidity of the air (RH), collected in the dry season (June to November) and wet season (December to May) using Pennsylvania light traps, in areas of savannah in the Alter do Chão Environmental Protection Area, June 2014 to May 2015.

Characterization of fauna between seasons

In the dry season there were 222 specimens (N) distributed across 26 species (S), with 11 being exclusive to this period, with 174 males and 48 females. The month of September had the greatest abundance (N= 61), and the months of September and October had the greatest richness (S= 13), with June being the month with the lowest N (11) and S (4) (Table 1 and Figure 3).

The Shannon diversity and uniformity indices were ($H' = 2.40$), and ($U = 0.726$), respectively, and the Berger- Parker dominance index was ($BP = 0.238$) (Table 2).

Four species were eudominant: *Isognathus caricae* (N= 53), *Cocytius duponchel* (N= 36), *Enyo lugubris* (N= 34), and *Isognathus menechus* (N= 34). There were 11 rare species encountered (42% of the total collection in this period).

The richness estimate for this season showed that this sampling collected between 76% and 90% of expected species. The ACE estimator yielded 39 species and Jackknife 2 estimated 34 (Table 2), and this result supports those from the species accumulation curve which continued rising (Figure 2b).

In the wet season 152 specimens (N) distributed across 24 species (S), with 8 being exclusive to this period, with 124 males and 28 females. The month of January had the greatest richness and abundance (S= 16, N= 48), and the month of February was the month with the lowest N (12) and S (6) (Table 1 and Figure 3).

The Shannon diversity and uniformity indices were ($H' = 2.55$), and ($U = 0.801$), respectively, and the Berger- Parker dominance index was ($BP = 0.230$) (Table 2), and the t-test for the comparison of the Shannon diversity indices between the two seasons was insignificant ($t = -1.368$).

The eudominant species were *Isognathus caricae* (N= 35), *Enyo lugubris* (N= 24), *Callionima parce* (Fabricius, 1775), *Erinnyis ello ello* (Linnaeus, 1758) and *Isognathus menechus* (N= 14). There were 8 rare species encountered (33% of the total collection in this period).

The richness estimates for this season showed that this sampling collected between 53% and 83% of expected species. The Bootstrap estimator yielded 29 species and Jackknife 2 estimated 45 (Table 2), and these results support those from the species accumulation curve which continued rising (Figure 2c).

Discussion

Characterization of the fauna

The abundance of Sphingidae in the ACEPA (N= 374) was greater than in Amazon savannah in Roraima (Motta et al., 1991), open forest savannah in the Tabuleiro Paraibano (Darrault & Schlindwein, 2002), the

semi-arid Caatinga biome and swamplands in Paraíba (Gusmão & Duarte, 2004), in the Atlantic Forest (Duarte JR & Schlindwein, 2008) and also in a few areas of forest in the Amazon (Motta & Xavier Filho, 2005; Hawes et al., 2009). However, the results for abundance in this study were inferior to those for forest in the Amazon (Motta et al., 1991; Motta et al., 1998; Motta & Andreazze, 2001, 2002; Camargo et al., 2016; Lourido, Motta, Graça, & Rafael, 2018), in the Atlantic Forest by Marinoni, Dutra, and Mielke (1999), and in Caatinga by Duarte JR and Schlindwein (2005b). Compared to areas of savannah, the results from the current study are greater than those from Amorim, Ávila, Camargo, Vieira, and Oliveira (2009) in the region of the Mineiro Triangle on the border of the State of Minas Gerais in the southeast of Brazil (Table 3).

Table 3. Inventories that were used to compare Sphingidae fauna collected in two seasons (dry and wet) using Pennsylvania light traps, in areas of savannah in the Alter do Chão Environmental Protection Area, Pará, Brazil.

Vegetation formation / Biome	Trap	Sample	Richness	Abundance	Reference
Amazon rainforest	Malaise, Pennsylvania light trap and occasional lighted wall	9	58	471	Motta et al. (1991)
Amazonian Savannas	Mixed mercury lamp on a wall	10	13	103	Motta et al. (1991)
Atlantic forest	ELSAQ light trap - mixed mercury lamp 160W	65	55	813	Marinoni et al. (1999)
Upland rainforest	Illuminated white cloth - mixed mercury lamp 250W	40	61	1.758	Motta et al. (1998)
Amazon rainforest	Illuminated white cloth - mixed mercury lamp, UV BL and BLB	93	79	2.362	Motta and Andreazze (2001)
Amazon rainforest	Illuminated white cloth - mixed mercury lamp 250W, UV BL and BLB	33	69	575	Motta and Andreazze (2002)
Open Savanna area	Illuminated white cloth - black light lamp and entomological net	14	24	136	Darrault and Schlindwein (2002)
Caatinga and Brejo	Luiz de Queiroz light trap - fluorescent lamp 20W UV BL	48	19	326	Gusmão and Duarte (2004)
Atlantic forest	Illuminated white cloth - mercury lamp 160W BL	24	23	89	Duarte JR and Schlindwein (2005a)
Amazon rainforest	Illuminated white cloth - mixed mercury lamp 250W	27	46	295	Motta and Xavier Filho (2005)
Caatinga	White wall - mercury-vapor lamps 160W	28	20	593	Duarte JR and Schlindwein (2005b)
Atlantic forest	White wall - mercury-vapor lamps 250W	24	50	369	Duarte JR and Schlindwein (2008)
Cerrado	Illuminated white cloth - two mixed mercury lamps 250W	15	49	408	Amorim et al. (2009)
<i>Eucalyptus</i> plantation and Amazon rainforest	Illuminated white cloth - mercury vapor lamp 160W and fluorescent lamp 12W BL	30	39	102	Hawes et al. (2009)
Atlantic forest (forest remnant, sugar cane plantations and pastures)	Illuminated white cloth - mercury vapor lamp 250 W	27	31	277	Primo, Duarte, and Machado (2013)
Amazon rainforest	Illuminated white cloth - two mercury vapor lamps 250W	149	90	9.048	Camargo et al. (2016)
Amazon rainforest	Illuminated white cloth - a mercury lamp and an ultraviolet bulb (UV-BLB)	36	52	1748	Lourido et al. (2018)

The richness ($S = 34$) sampled in the ACEPA corresponds to 31% of that found in the State of Pará (Moss, 1920; Motta & Soares, 1997; Hawes et al., 2009; Camargo et al., 2016). When compared to results from studies done in other regions of the Brazilian Amazon, the richness in the ACEPA is superior to that in a savannah in the Pacaraima Mountains studied by Motta et al. (1991), and inferior to the richness found in Amazonian forests (Motta et al., 1991; Motta et al., 1998; Motta & Andreazze, 2001, 2002; Motta & Xavier Filho, 2005; Hawes et al., 2009; Camargo et al., 2016; Lourido, et al., 2018) (Table 3). In comparison with other biomes, the richness of Sphingidae in the ACEPA was superior to that found by Darrault and Schlindwein (2002) in an open forest savannah, and to that reported by Duarte JR and Schlindwein (2005b) in the caatinga. The richness found in the current study was also greater than that reported by Gusmão and Duarte (2004) in an area of the semi-arid Caatinga biome and swampland, and inferior to that found in a savannah (Amorim et al., 2009) (Table 3).

The striking differences between the values for diversity and richness between the study sites mentioned above could be related to the collection technique as influenced by the geographical characteristics of the

region studied. For example, the savannah studied in the current study is made up of patches of savannah inserted in the tropical forest, and due to this fact low-power light traps were used in order to reduce the radius of the sampled area, but in the studies mentioned above light traps with a larger radius of luminosity, and therefore of capture potential, were used (Table 3). It was also observed in this study that sample size is a key factor for the determination of greater richness and abundance.

The occurrence of a larger number of males in our samples is a common pattern for hawkmoths as found in other studies (Motta et al., 1991; Motta et al., 1998; Motta & Andreazze, 2001, 2002; Duarte JR & Schlindwen, 2005a; Primo et al., 2013; Lourido et al., 2018).

The diversity indices compared to those from Gusmão and Duarte (2004) are higher for the Shannon index in the swampland ($H' = 2.32$) and the Caatinga ($H' = 1.65$). The Shannon uniformity index in this study was inferior to that of the swampland ($U = 0.86$) and superior to that of the semi-arid Caatinga ($U = 0.63$), demonstrating that the species in the Alter do Chão savannah have greater similarity in abundance compared to that of the Caatinga and less than that of the swampland. The Berger-Parker dominance index was inferior to that of the Caatinga ($BP = 0.53$) and similar to that of the swampland ($BP = 0.22$), demonstrating that the occurrence of dominant species was more constant in the Caatinga and similar to that of the savannah and the swampland. The results for the swampland and the Caatinga were found using similar sampling techniques to those used in the savannah; however, the fact that the results found in the current study are similar to those of the swampland could be explained due to the proximity of the sampling area to the forest.

The estimator Chao1 was the one that was the least representative of the samples, and the results from this estimator were less representative than those from the study by Amorim et al. (2009). When compared to estimates from other studies done in the Amazon, cited by Camargo et al. (2016), our estimate is 99% equal to the estimate made by Motta et al. (1991) (Maracá Island), and less representative compared to Camargo et al. (2016), Motta et al. (1998), Motta and Andreazze (2001, 2002), Motta and Xavier Filho (2005), but superior to the estimates of Motta et al. (1991) from the Pacaraima Mountains, and Hawes et al. (2009).

Isognathus caricae was the most abundant species in our study, different than the results from other studies in the Amazon (Motta et al., 1991; Motta et al., 1998; Motta & Andreazze, 2001, 2002; Hawes et al., 2009; Lourido et al., 2018), demonstrating that the occurrence of species differs according to habitat type.

In general, the composition of the fauna of Sphingidae in the ACEPA is similar to that found in forest areas (Camargo et al., 2016). When species composition is compared to that found in other Amazonian savannahs (Motta et al., 1991) there are just 10 species in common. When compared to the savannah as a whole, the species *Eumorphia phorbis* (Cramer, 1775) and *Xylophanes loelia* (Druce, 1878) occur only in the Amazon region (Amorim et al., 2009; Darrault & Schlindwein, 2002; Camargo, Camargo, Corrêa, Vilela, & Amorim, 2018), a result that is justified by the fact that these species also occur in Amazon tropical forests.

The results for the correlations with climatic variables were similar to those from Amorim et al. (2009) with respect to temperature and abundance, and were different than those from Primo et al. (2013), who studied in forest fragments wherein they obtained a positive correlation between annual precipitation and richness and abundance of species.

Characterization of the fauna during the wet and dry seasons

The greater indices of abundance and richness that occurred in the wet season are contrary to the results reported by Primo et al. (2013), Amorim et al. (2009), Duarte JR and Schlindwein (2005a) and Duarte JR and Schlindwein (2005b), studies that reported that the wet season has greater richness and abundance. These authors cite three probable factors that justify this greater richness and abundance of Sphingidae: first, this seasonality could be influenced by the availability of food sources for caterpillars; second, the flowering of plants that could be potentially pollinated coincides with hawkmoth population increases; third, that there is migration between areas within the mosaic of vegetation formations between biomes or adjacent areas.

In both the wet and dry seasons there was a greater occurrence of males, with a value of 4.4:1 for the ratio wet : dry seasons, and in the dry season this ratio was 3.6:1 in spite of the fact that the absolute number of males and females was greater during the dry season.

The Shannon diversity and uniformity indices were higher in the wet season, and the Berger-Parker dominance index was more representative of the sampled population in the dry season. The t-test for the comparison of the Shannon diversity indices between the two seasons was insignificant.

The dry season had a greater number of rare species, different than the result reported by Amorim et al. (2009), wherein a larger number of rare species was found in the wet season. Three species were eudominant during both seasons (*Isognathus caricae*, *Enyo lugubris lugubris* and *Isognathus menechus*). *Cocytius duponchel* was eudominant only in the dry season, and *Callionima parce* and *Erinnyis ello ello* were eudominant only in the wet season. The wet season also showed greater estimates for species richness with estimators showing that the number of species sampled in this season was much closer to the expected richness, with the Jackknife 2 estimator being the only one that yielded a greater number of species for the dry season.

Conclusion

The richness, abundance and diversity found in this study contribute significantly to the knowledge of the Sphingidae fauna in the Amazon and also to the knowledge of the seasonality of Sphingidae in Amazonian savannah areas, which is an environment that suffers impacts that compromise the existence of this ecosystem and its fauna.

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